Dry beneficiation of high loss-on-ignition fly ash

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Abstract

Dry beneficiation of three high loss-on-ignition (LOI) fly ashes were conducted. The combination of two different types of dry separation techniques—ultrasonic sieving and triboelectrostatic separation—were used for this study. The results indicate that a simple separation of unburned carbon from fly ash is achievable at particle sizes of 149, 74 and 44 μm, and screening could be utilized as the rough separation mechanism for fly ash. Subsequently, triboelectrostatic separations were conducted on these different particle size fractions of the fly ash and indicated that the final carbon content in the products, as low as 2.5% or as high as 60%, can be further adjusted with the combination of dry sieving and triboelectrostatic separation.

1. Introduction

As power plants strive to comply with the Clean Air Act by installing equipment such as low NOx burners, this has usually been accompanied by an increase in the unburned carbon in fly ash. The widest application for fly ash continues to be for cement replacement in ready-mix concrete. However, increases in carbon content can make the fly ash unsuitable for this application. The ASTM C618 specification limits loss-on-ignition (LOI) to 6%, largely due to the fact that higher LOI levels often result in discoloration, poor air entrainment, and segregation of mix components. Air entraining agents (AEA) are used to stabilize the small air bubbles which provide freeze/thaw resistance in concrete. The presence of higher carbon levels can adsorb these surfactants, often resulting in the need for undesirable large AEA dosages [1]. The ability to efficiently extract high purity carbon or ash is important in the development and application of cost-effective beneficiation technologies for the production of value-added products. The post-combustion beneficiation can generate valuable unburned organic and inorganic fly ash products, and these two constituents can be collected and used as commercial products. The unburned organic fraction can be recycled back to the burner as fuel or used as a catalyst, activated carbon, or catalyst support. The purified inorganic fraction can be

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utilized as a cement additive [2–6]. Improved beneficiation and utilization schemes for fly ash can transform it from a waste material, with associated disposal costs, to a valuable product.

The constituents of fly ash vary in size (most of the unburned carbon is contained in the larger size fraction of the fly ash as opposed to minerals), density, electrostatic, physical, and chemical properties making the separation of the fly ash a very difficult task. However, a systematic combination of separation techniques based on the differences in size, density, electrostatic, and physical properties may achieve the difficult separation task of extracting valuable products from fly ash.

Sieving fly ash capitalizes on the tendency of carbon and mineral to have different particle size distributions within fly ash. Carbon and mineral particle size distributions widely vary and typically there appears to be a clear trend. For instance, fly ashes sieved through a 325-mesh screen exhibit a measurable reduction in LOI [7,8]. Electrostatic beneficiation of fly ash to separate unburned carbon has been investigated widely as an alternate to the other post-combustion cleaning technologies [9–12]. During triboelectrification, organic and mineral particles are charged with opposite polarity and separated by using an electrostatic separator. When two materials are in contact, electrons move until the energy level of electrons in each material at the interface is equalized. The material with a higher affinity for electrons gains electrons and charges negatively, while the material with the lower affinity loses electrons and charges positively. On contact with metal (copper), the organic particles become positively charged, and the inorganic mineral particles become negatively charged. The charged particles are then passed through an electrostatic separator consisting of two conducting electrodes, across which a high voltage is applied. Organic (unburned carbon) particles are attracted to the negative plate, and minerals are deposited to the positive plate.

The types of physical separation techniques that were utilized in this study include a dry ultrasonic sieve and a parallel plate tribo-separator (Fig. 1). This study involved the dry separation of a variety of coal fly ash samples from commercial power plants that contain varying amounts of unburned carbon. The optimum combination of these techniques can achieve the desired separation of the value-added products from fly ash.

2. Experimental

In an attempt to generate value-added products, the fly ashes were handled in their dry state and passed through ultrasonic sieving ($+100$, $+200$, and $+325$ mesh) to separate the finer fraction (mostly ash) from the coarser fraction (mostly carbon). These were analyzed for carbon and mineral content. The selected size fractions were subjected to triboelectrostatic separation to further enhance or to deplete carbon content to produce the desired products. The finer fraction was used as the feed to the tribo parallel plate separator for further reducing the carbon content so this product can be used as a cement additive. The coarse fraction was utilized as the feed to the

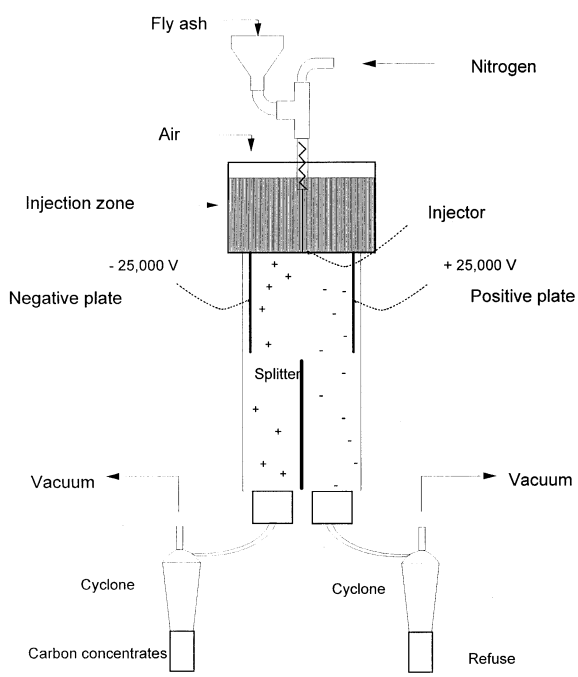

Fig. 1. Schematic diagram of a triboelectrostatic parallel plate separator.

parallel plate separator to obtain a carbon concentrated product.

A deblinding sieving system, model RBF equipped with 100 (149 μm), 200 (74 μm) and 325 (44 μm)-mesh screens manufactured by MM industries, Inc., that utilized high speed gyration (up to 3450 RPM) and ultrasonic energy (130 watt × 40 KHz transducers) was used for the size separation.

The parallel plate separator used for this study consists of a venturi feed system driven by pressurized nitrogen gas, an adjustable injection zone, and a high voltage separation section (Fig. 1). The fly ash particles pass through the venturi feeder and become charged in this turbulent flow zone by contact with the copper tubing and with each other. These charged particles then are forced out the nozzle in a ribbon of entrained particles approximately 7.62 × 0.3175 cm. This plume of particles is directed between two parallel charged plates 15.24 cm long and 7.62 cm apart. For fly ash separations this unit is operated at + or − 25,000 volts on the separator plates. The positively charged unburned carbon particles are attracted to the negative electrode and the negatively charged mineral particles are attracted to the positive electrode. A splitter is placed 15.24 cm downstream from the nozzle to separate the unburned carbon rich and ash rich fractions and direct them to two collection cyclones. The entire separator is swept with laboratory air by applying vacuum to the outlets of the collection cyclones. Sweep flow enters the separator through flow straighteners around the nozzle to control the flow in the separator section. This separator has a capacity of about 8 kg/h in continuous operation and can be used in the batch mode using as little as 100 g fly ash feed. The recovery efficiency of the cyclones is typically greater than 95% [12]. In this application, the batch mode separations are done with the adjustable injector in five positions with respect to the fixed position splitter (position center, C), displaced 0.635 (P1) or 1.27 cm (P2) toward the positive plate (position positive) and displaced 0.635 (N1) or 1.27 cm (N2) toward the negative plate (position negative). The concentrated unburned carbon (attracted to the negative electrode) generated in these five runs, together with the feed, is then analyzed for carbon and ash content to yield a performance curve. These curves can be used to evaluate the potential of fly ash for separation and to compare the responses of fly ash from different sources.

These experimental configurations were used to study the separation on three types of fly ashes. One was obtained from the Gulf power plant, Florida, with a carbon content of 12.91 wt.%. The other two were acquired from Shawville and Glen Lyn power plants, Pennsylvania, with carbon contents of 14.20 and 11.83 wt.%, respectively. All samples were low moisture powders which fed easily to the separator and all were separated as received. The carbon concentrate and mineral concentrate fractions were collected on the negative and positive plates respectively. After collection and homogenization the fractions were analyzed for carbon and ash content.

3. Result and discussion

The dry ultrasonic sieving of the fly ashes obtained from Gulf Power, Shawville and Glen Lyn Power plants were conducted on the as-received samples prior to further triboelectrostatic separation. The results from the size separation were tabulated in Table 1. Depending on the source, the majority of the fly ashes passed through the 200 mesh screen (74 μm). For the Gulf fly ash, the carbon content was 12.77 wt.% for those fly ash particle sizes ranging between 44 and 74 μm, though it only accounted for 26.74 wt.% of the total parent fly ash. The carbon content was further reduced to 6.56 wt.% for fly ashes passing through a 325-mesh screen (44 μm) and it accounted for 56 wt.% of the parent fly ash. For the larger size fly ash particles, a 28.82 wt.% carbon content was observed on fly ash particles with sizes between 74 and 149 μm, and it consisted of 14.91 wt.% of the total fly ash. Furthermore, a fraction of a high carbon content of 45.92 wt.% was retained for fly ash particles with particle sizes larger than 149 μm. However, the collected high carbon content portion was a very small fraction, 2.31 wt.%, of the total as-received fly ash. Similar trends were found on the fly ashes

Table 1
Fly ash separations via sizing

Ash sources	Ash (wt.%)	Carbon (wt.%)	Parent ash (wt.%)
Gulf raw	86.9	12.91	100
Gulf +149 μm	53.88	45.92	2.31
Gulf 74–149 μm	70.97	28.82	14.91
Gulf 44–74 μm	87.06	12.77	26.74
Gulf −44 μm	93.23	6.56	56.04
Shawville raw	85.49	14.2	100
Shawville +149 μm	63.03	36.66	7.84
Shawville 74–149 μm	80.02	19.74	21.64
Shawville 44–74 μm	85.61	14.15	23.4
Shawville −44 μm	93.62	6.08	47.12
American electric raw, Glen Lyn	87.96	11.83	100
American electric +149 μm	52.96	46.85	2.47
American electric 74–149 μm	74.15	25.58	13.86
American electric 44–74 μm	87.49	12.27	31.54
American electric −44 μm	93.89	5.87	52.13

obtained from Shawville and Glen Lyn Power. The fly ashes with the particles size of 74 μm or larger usually had a higher carbon content, 20 wt.% or higher. However, these larger particles only consisted of a small portion of the total fly ash, 30 wt.% or less. Fly ash with sizes between 44 and 74 μm had similar carbon content as their corresponding parent fly ash. The smaller size fly ashes, 44 μm or less, had a lower carbon content of 6.08 and 5.87 wt.% for the fly ashes obtained from Shawville and Glen Lyn, respectively. But, they accounted for close to 50 wt.% of their parent fly ashes.

Therefore, size-based separations can be effectively applied to the fly ashes tested in this study. It is evident that significant reductions in carbon content could be realized using a 325 mesh screen (44 μm). At this size, the carbon content can be reduced from 12.91 wt.% from the parent fly ash to 6.56 wt.% at a recovery of over 56% for the Gulf ash studied. Similar trends were observed for the fly ash obtained from Shawville (14.2 wt.% carbon) and Glen Lyn Power (11.83 wt.%). The carbon content can be reduced to 6.08 and 5.87 wt.% at a recovery of 47.12 and 52.13%, respectively, for Shawville and Glen Lyn power fly ashes. The results suggest that a simple size separation via ultrasonic sieving could generate samples with various carbon contents.

Subsequently, triboelectrostatic batch mode separations were conducted on these separated fractions derived from the Gulf fly ash. In this study, we used a parallel plate separator to evaluate a variety of fly ash with different sizes so that their performance curves could be compared. The concentrated unburned carbon (attracted to the negative electrode) and enhanced ash generated in five different injector positions (N1, N2, C, P1, and P2), together with the feed, are then analyzed for carbon and ash content to yield a performance curve. These curves can be used to evaluate the potential of fly ash for separation and to compare the responses of fly ash for different particle sizes. The results are illustrated in Figs. 2 and 3.

The quality of this triboelectrostatic separation can be determined by measuring the cumulative recovery of ash in the products collected from the positive plate and unburned carbon content (LOI) as a function of the position of the injector in the parallel plate separator (Fig. 2). The yield of ash -rich matter and unburned carbon content on the mineral-rich side are presented as a percentage of the total amounts of each component in the different particle size feeds. The similar LOI versus Ash Recovery trends were observed on both the raw Gulf ash feed and the Gulf ash feed with particle sizes range from 44 to 74 μm. A mineral-

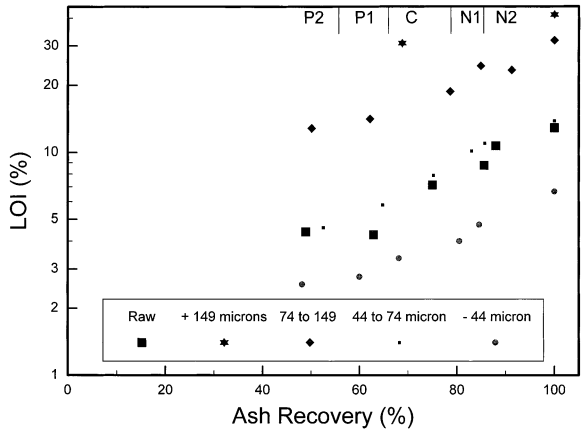

Fig. 2. Ash recovery versus LOI content for Gulf fly ash from a (+) plate of a parallel plate separator (■, raw fly ash; ★, sizes above 149 μm; ◆, sizes between 74 and 149 μm; ■, sizes between 44 and 74 μm; ●, size below 44 μm).

rich product which contained 4.27% of unburned carbon along with an ash recovery of 63% could be achieved by adjusting the position of the injector to the positive 0.635 cm position (P1). This significant reduction of the unburned carbon content from 12.91% in the feed to 4.27% in the ash-rich product is at the expense of the recovery of the mineral matter. Similarly, a product with unburned carbon content of 4.5 and 52% of ash recovery (P2) could also be collected from the

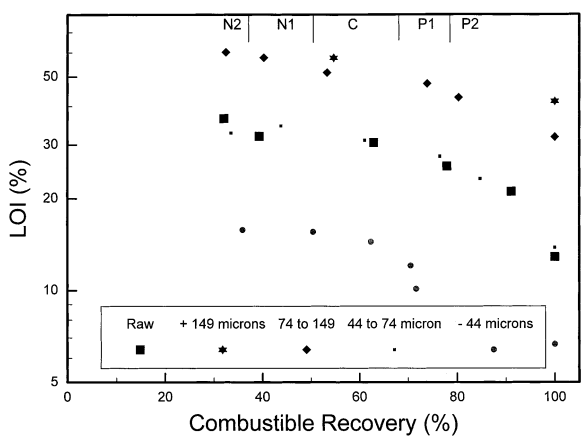

Fig. 3. Combustible recovery versus LOI content for Gulf fly ash from a (−) plate of a parallel plate separator (■, raw fly ash; ★, sizes above 149 μm; ◆, sizes between 74 and 149 μm; ■, sizes between 44 and 74 μm; ●, sizes below 44 μm).

positive side of the parallel plate separator for the feed with particle sizes range between 44 and 74 μm. However, the significant reduction of carbon content from the products could be obtained with the feed of particle sizes of 44 μm or less. A product with unburned carbon content of 2.56 and 48% of ash recovery (P2) could be collected from the positive side of the parallel plate separator. This collected product is ready as a cement source without further purification. For larger particle size feeds (74 and 149 μm), the quality of the separation was not as successful as that of smaller particles size feeds fly ash. The carbon content of the product could be reduced to 12.8 wt.% with a 50% ash recovery (P2), compared to the feed with carbon content of 31% with particle sizes range between 74 and 149 μm. It was noticed that the significant reducing of the unburned carbon content in the products could be achieved by adjusting the position of the injector from N2 to P2. However, there is a tradeoff between the unburned carbon content and ash recovery. Considering the reduction of the unburned carbon in the product, the optimal condition for separation could be achieved by using the feed with particle sizes of 44 μm or less and the position of the injector in P2 position.

The products collected from the negative side of the separator showed the opposite trends (Fig. 3). For the raw Gulf ash feed, a carbon-rich product which contained 33% of unburned carbon along with a combustible recovery of 39% could be achieved by adjusting the position of the injector to the negative 0.635 cm position (N1). This significant enhancement of the unburned carbon content from 12.91% in the feed to 33% in the carbon rich product is at the expense of the recovery of the combustible matter. Fig. 3 also illustrates the results obtained from other different particle size feeds. A similar trend as seen from the parent fly ash was observed for the feed with particle sizes that range between 44 and 74 μm. A product with unburned carbon content of 32 and 33% of combustible recovery (N2) could be collected from the negative side of the parallel plate separator. However, the significant enhancement of carbon content from the products could be accomplished with the feed of particle sizes of

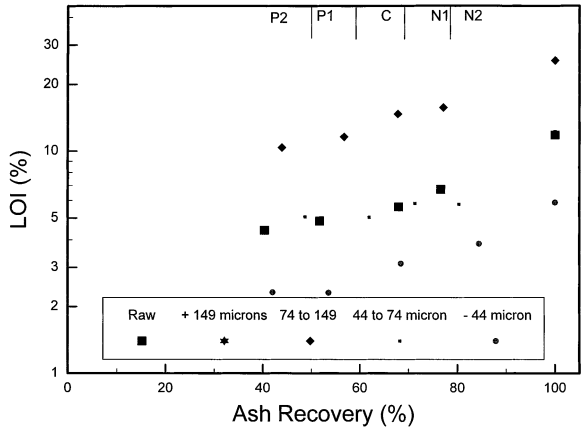

Fig. 4. Ash recovery versus LOI content for Glen Lyn fly ash from a (+) plate of a parallel plate separator (■, raw fly ash; ★, sizes above 149 μm; ◆, sizes between 74 and 149 μm; ■, , sizes between 44 and 74 μm; ●, size below 44 μm).

74 μm or larger. A product with unburned carbon content of 60 and 32% of combustible recovery (N2) could be collected from the negative side of the parallel plate separator with the injector in the negative 1.27 cm position (N2). This collected product is ready for carbon applications such as a catalyst, reburning as a fuel or as a catalyst support. For smaller particle size feeds (44 μm or less), the quality of the separation is not as good as that of larger particles size feeds. The carbon content of the product could be enhanced to 15.8 wt.% with a 36% of combustible recovery (N2) for the feed with carbon content of 6.8% with particle sizes ranges between 74 and 149 μm. It was observed that an enhancement of the unburned carbon content in the products could be obtained by adjusting the injector to the N2 position. Nevertheless, this would reduce the degree of recovery.

Figs. 4 and 6 show the LOI content versus ash recovery collected from the positive plate for Glen Lyn and Shawwell Ash, respectively. These tests were conducted in the same manner as the Gulf Fly ash. The general recovery trends of fly ash with particle sizes between 44 and 74 μm are similar to that of raw fly ashes for Glen Lyn fly ash. Again, similar phenomena were observed for Gulf fly ash. Furthermore, low carbon content products can also be collected from the feed with a smaller size; − 44 μm. A product with low unburned carbon content of 2.32 and 42% of ash recovery (P2) could be collected from the positive side of the parallel plate separator from Glen Lyn fly ash (Fig. 4). A similar LOI content of 2.3% (P2) was also obtained from the Shawwell fly ash (Fig. 6). These products are suitable for cement application without further beneficiation. For the larger sizes, 74–149 μm feeds, for both Glen Lyn and Shawwell ashes, a product with 10% LOI (P2) can be collected from the separator (Figs. 4 and 6).

Figs. 5 and 7 illustrate the LOI content versus combustible recovery collected from the negatively plate for Glen Lyn and Shawwell Ash, respectively. All of these recovery curves demonstrate a similar trend. The general recovery trends of fly ash with particle sizes between 44 and 74 μm are similar to that of raw fly ashes for Glen Lyn fly ash. A product with unburned carbon content of 61 and 42% of combustible recovery (N2) could be collected from the negative side of the parallel plate separator for Glen Lyn fly ash (Fig. 5). A high carbon content product can be collected from a feed with particle size between 74 and 149 μm for both Glen Lyn and Shawwell Ash (Figs. 5 and 7).

These results indicate that the final carbon content (less than 3% for − 44 μm feed or higher than 60% for 74–149 μm feed) in the products

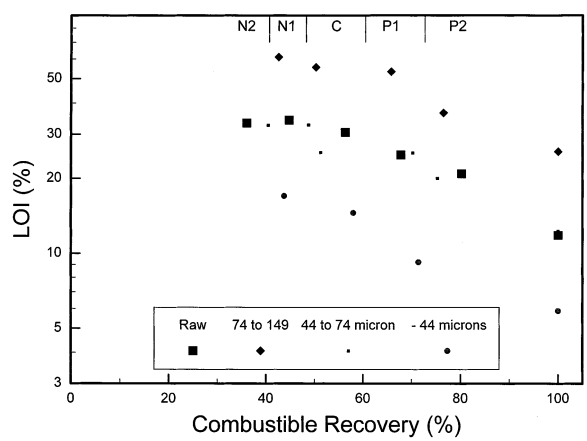

Fig. 5. Combustible recovery versus LOI content for Glen Lyn fly ash from a (−) plate of a parallel plate separator (■, raw fly ash; ◆, sizes between 74 and 149 μm; ■, , sizes between 44 and 74 μm; ●, sizes below 44 μm).

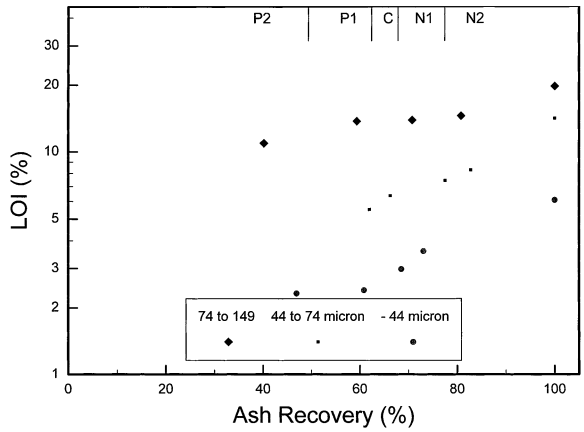

Fig. 6. Ash recovery versus LOI content for Shawwell fly ash from a (+) plate of a parallel plate separator (◆, sizes between 74 and 149 μm; ■, sizes between 44 and 74 μm; ●, size below 44 μm).

can be adjusted with the combination of dry ultrasonic sieving and triboelectrostatic separation. The results were obtained by the single-pass separation experiments. A multiple passes separation via the triboelectrostatic separator might generate the separated products with a carbon content much higher than 60% or much less than 3%. The combination of these methods, might be customized and implemented in a cost-effective manner to meet the beneficiation needs of fly ash producers.

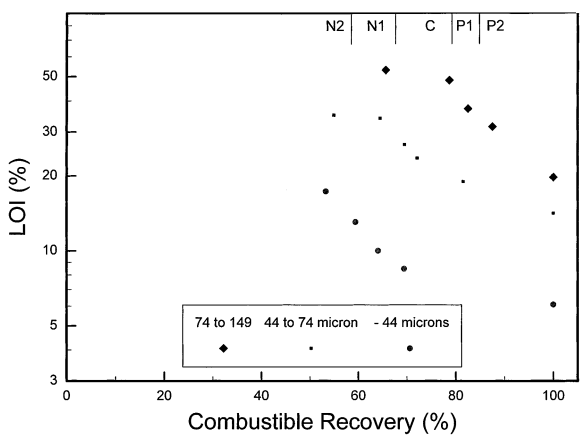

Fig. 7. Combustible recovery versus LOI content for Shawwell fly ash from a (−) plate of a parallel plate separator (◆, sizes between 74 and 149 μm; ■, sizes between 44 and 74 μm; ●, sizes below 44 μm).

4. Conclusions

In the recovery of different materials from fly ash, a concept exploiting large differences in particle size and triboelectrostatic properties was explored The results indicate that a simple separation of carbon from fly ash is achievable at particle sizes of 149, 74 and 44 μm and screening should be utilized as the rough separation mechanism for fly ash. Subsequently, triboelectrostatic separations were conducted on these different particle size fractions of the fly ash and indicated that the final carbon content in the products, as low as 2.3% or as high as 60%, can be fine-tuned with the combination of dry sieving and triboelectrostatic separation. The combination of ultrasonic sieving and triboelectrostatic separations utilized in this study are able to provide effective separation in producing an ash-rich stream for concrete additive applications as well as a carbon rich stream.

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